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A FAST RIGOROUS METHOD FOR INDUSTRIAL PLANNING

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SUMMARY

1. Introduction

2. Industrial Planning

3. Cost Function

4. Optimization Algorithm

5. Conclusion

References (4)

ABSTRACT

The analytical method presented here is a rigorous and complete solution to industrial planning. It is simple to implement and several orders faster than any existing heuristic procedures. It makes practical and concrete optimal planning. It integrates short term and long term plannings in that optimal short term plans are successive steps of implementing the optimal long term plan. The optimality criterion of the method unequivocally expresses the productivity of investments in plants. The corresponding cost function permits a consistent comparison of options as widely diverse in technical features (production capacity, service life, etc.) as can exist.

Key Words: Planning, Optimal Planning, Telecommunication Network, Transport Network, Economic Evaluator, Equipment Selection, Investment.

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1. INTRODUCTION

The deciding role of planning in modern economic systems and the unresolvable inadequacies of existing planning procedures make it necessary to rethink the problem. This study presents a revolutionary view and an effective method of industrial planning.

The fundamental flaw of past studies on industrial planning (Ref.1)[1] is that they fail to properly model the long term effect of an investment decision. The evaluators devised to this effect either are too simplistic (pay back period, equivalent cost) or involve concepts which are remote from investment realities (net present value, present worth of annual charges, average internal return rate). This results in planning procedures which are unnecessarily complex and imply unrealizable hypotheses. In fact, these procedures inherently contain technical and logical contradictions. They also create combinatorial problems for which only heuristic search techniques exist and are of uncertain approximation.

To make the most of these availabilities, current practices apply two or more evaluators simultaneously and then juggle with the ambiguous or contradictory results to draw a conclusion which is much of the planner's own intuition. This seriously prejudices the benefit and scope of planning studies.

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1 Ref.1 is cited as the most recent publication known to this author on the subject.

Controlling the long term cost of serving the forecasted demand is the main concern of industrial planning. This cost is expressed in Section 3.1 as the "selling price" to charge each demand unit so that the resulting gross revenues cover all operating expenses and repay all capital expenditures with due returns. It is comprehensively formulated (Section 3.2) in terms of the operating expenses, the capital expenditures, the return rate to be realized or maximized (Section 2.2.1 and 2.2.2), the expected sale volume as a function of time, the production capacity and service life of the plant. Such a cost unequivocally measures the productivity of investments in plants, i.e. the technico-economic (cost, production capacity, performance, service life) fitness of the plant in meeting the demand to be served.

The corresponding gross revenues are then minimized at any time over an indefinite period to determine the optimal sequence of decisions on plants (Section 4). The solution so produced is rigourous operationally, analytically and logically.

This analytical method is fast and simple to implement. It makes optimal planning concrete and practical. It integrates short term and long term plannings. Indeed, the optimal short term plans to be executed are successive steps of implementing the optimal long term plan to be determined for overall evaluation of the project. Through producing the absolute minimum for the selling price per unit, the method is decisive in evaluating projects, in particular, their viability.

2. INDUSTRIAL PLANNING

2.1 Basic Problem

The basic problem of industrial planning can be stated as follows:

a) Let the demand be forecast as a function of time over some period (forecast period);

b) Let an option for meeting the demand be characterized by the operating expenses and capital expenditures, the maximum production capacity and its installation modules, the life cycle, the required floor space and other, if any, technical features which have bearings on the option selection;

c) Let the set of these options be given as a function of time, i.e. whenever an additional production capacity is needed (decision time);

d) Let the physical and financial constraints be specified as functions of time;

Then determine the sequence of options which meets the demand at any time and maximizes the productivity (or profitability) of the required investments.

In the sequel, such a planning problem is said to define a project; its solution determines the optimal implementation of the project.

The option selected at a given time will be called a decision. A decision is then a production entity defined by the option characteristics (enumerated in paragraph b).

A decision is to be made when an additional production capacity is needed to meet the demand. Its maximum production capacity then determines the time of the next decision. The interval between the decision time and the time of the next decision will be called decision fill period and the length of this interval, the decision length.

Determining the optimal implementation of a project is fundamental in planning. Indeed, only on the cost (or more specifically, the financial productivity) of the optimal implementation that it is proper and conclusive:

a) to evaluate a project and decide upon its viability,

b) to select projects and establish their priority,

c) to decide, in particular, between:

c.1) the status quo and the operations modernization,

c.2) the status quo and the production extension,

c.3) the plants modernization and the mere addition of production facilities.

In this global context, project planning, as defined above, is also fundamental to the general problem of resources planning.
The solution presented here has the following characteristics:

a) the productivity of a sequence of investments in plants is unequivocally characterized, not by a present value, but by a real time measure, the "required gross revenues" as a function of time over an indefinite period (Optimality criterion, Section 2.3).

b) the cost function involved permits a consistent comparison of options as widely diverse as can exist in production capacity, production or service features, maintenance features, service life etc...

c) the end of the planning period is left open so that the optimal decision sequence can be continued indefinitely along with future forecast extensions and its decisions are independent of the forecast period length.

2.2 Characterization of Investment Productivity

The capital expenditures incurred by a decision constitute a loan made to the corresponding plant (the borrower) regardless of their sources (internal funds, loans, shareholders' dividends etc.). They are expected to be repaid fully and with due returns. The plant service life is the repayment period; the time function of the demand determines the repayment pattern.

The net revenues derived from the plant production and these revenues alone are the repayment amounts. Specifically, it cannot be assumed that revenues from one decision are reinvested (for example at the "project internal return rate", as usually assumed) and finance future decisions.[2]

In evaluating and optimizing decision sequences, the long term effect of a decision must then be modelled so as to treat each decision as a separate (independent) financial operation. This will be referred to as: principle of financial independence of decisions.

The principals, the net revenues and the return rate of a decision, which, as just stated, specify a separate investment, are univocally related by the basic "loan repayment equation" (Section 3.2).

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2 This assumption is inherent to the classical evaluators: Net Present Value (NPV), Present Worth of Annual Charges (PWAC) etc..
The concept of present value (or worth) should be interpreted and applied exclusively in the context of loan repayment, out of which it originates and about which any investment evaluation necessarily is; namely:
An amount A paid in year n in repayment of a loan, contracted at time 0 and the interest r, repays only $A(1+r)^{-n}$ in principal. Used abstractly and indiscriminately as in current practices, the concept is misleading because it is devoid of investment meaning.

Two planning situations exist and are exclusive and mutually exclusive:

a) either the decision is required to realize a given rate of return ("required return rate" case, as will be referred to),

b) or the gross revenues are specified for the decision as a function of time over the decision service life ("given gross revenues" case).

The effective way of characterizing the investment productivity in these situations is analyzed below.

2.2.1 "Required Return Rate" Case

If a "required return rate" is given, then the unknown to be determined is the gross revenues that the decision is required to produce so that the given "required return rate" can be realized. Referred to as "required gross revenues", these revenues are determined by the "loan repayment equation" (Section 3.2) in the following conditions (which determine the repayment pattern).

Given the required return rate,
Given the operating expenses and capital expenditures incurred by the decision,
Given the decision service life,
Given the demand served by the decision as a function of time over the decision service life,
Then:

a) at any time, the "required gross revenues" are the product of the selling price per demand unit by the demand served by the decision,

b) after deduction of all operating expenses and taxes, the resulting net revenues repay the decision capital expenditures fully at the end of the decision service life and realize the given required return rate.

The lower the "required gross revenues" are, the lower is the selling price per demand unit (hence the over all production cost per unit) and the higher is the potential of securing the market (or, in regulated industries, of serving at minimum charge).

As the required gross revenues are proportionately related to the demand function, they rigorously characterize the decision fitness in costs and production performance to the demand to be served and the return rate to be realized. Therefore, they are an unequivocal real time measure of the productivity of the investments incurred by the decision.

The "required return rate" to be specified for a decision must be fixed in terms of the project risks and the money market conditions which prevail at the time of the decision. It must then vary from one decision to another if the project risks and money market conditions are to be properly represented. A constant "required return rate" for the entire project is therefore distorting. Such a concept of "project or corporate internal return rate" is also inconsistent with the principle of financial independence of decisions (Section 2.2).

The following can now be stated.

Given the "required return rate" as a function of decision time, minimizing the total required gross revenues of a project at any time over an indefinite period maximizes the long run productivity of investments and produces the project optimal implementation.

This states the optimization problem to be solved in the case of "required return rate".

2.2.2 "Given Gross Revenues" Case

If the gross revenues are specified for a decision, then the unknown to be determined is the rate of return.
Given the decision service life,
Given the operating expenses and capital expenditures incurred by the decision,
Given the gross revenues estimated for the decision as a function of time over its service life,

Then the return rate of the decision is determined by the loan repayment equation where the net revenues are derived by deducting all operating expenses and taxes from the given gross revenues(Section 3.2).

The gross revenues of a decision are necessarily proportionate with the demand served. The decision return rate then depends on the pattern according to which this demand varies with time (demand pattern) and, as a general rule, varies along the project from one decision to another.

Thus in evaluating and optimizing decision sequences where gross revenues are specified, gross revenues must be partitioned to the various decisions proportionately with the demand served by each of them; and the return rate, consequently and separately determined for each decision. This is consistent with the principle of financial independence of decisions (Section 2.2). An average return rate for the whole sequence is meaningless since it is not unique.

The following can now be stated:

Let the gross revenues be specified for a project as a function of time; maximizing the return rate for each decision to be made over an indefinite period maximizes the long run profitability (hence productivity) of investments and produces the project optimal implementation.

As will become evident in Sections 3 and 4, the optimization problem corresponding to the above is solved by solving the problem of Section 2.2.1 for various "required return rates" until the "required gross revenues" so determined equal the given gross revenues.

This explains why in Section 2.3, the optimality criterion is stated exclusively for the case of "required return rate".

2.2.3 Revised "Pay Back Period" Evaluator

The two planning situations analyzed above are exclusive and mutually exclusive. Any other situation can and must be resolved into one of them. The impossibility to do so always indicates that the planning problem is inconsistently stated.

The service life of a decision is, in general, to be fixed in terms of the project long term risks, the foreseeable evolution of technologies and the decision technical characteristics such as: frequency of failures, maintenance cost, obsolescence pace, etc.

A need for rapid cash turn-around and/or a high uncertainty in the long run may however make it desirable to decide the viability of a one decision project on the basis of a pay back period fixed much shorter than the technical life cycle of the decision.

In such a case, the evaluation problem should be solved as follows:

Let the pay back period be given,
Let the decision capital expenditures and operating expenses be restricted to the given pay back period; let the capital depreciation allowances claimed during the pay back period be those determined for the regular service life of the decision.
Let the "required return rate" be given;
Let the gross revenues be estimated as a function of time during the given pay back period;
Let the "required gross revenues" during the given pay back period be determined for the given required return rate, the capital expenditures and operating expenses restricted to the pay back period and the service life equal to the pay back period.

Then, the project is viable if these "required gross revenues" at most equal the gross revenues estimated during the pay back period.

This solution ensures that all capital expenditures are repaid fully and with the required returns even if the project is liquidated without any salvages at the end of the pay back period.

2.3 Optimal Planning: Definition and Optimality Criterion

In accordance with the analysis of Section 2.2.1, the following is defined to state the optimality criterion for the basic planning problem (Section 2.1).

Let the "required return rate" be specified as a function of decision time (variable "required return rate");

Then a sequence of decisions is optimal if, over an indefinite period:

1) it meets the demand at any time, ensures a given quality of service or product, satisfies the specified physical and financial constraints and

2) its total "required gross revenues" (Section 2.2.1 and 2.2.2.) are minimum at any time while:

   a) covering all operating expenses (management, labour, floor space, maintenance, material, taxes, etc.)

   b) repaying all capital expenditures incurred by each decision fully at the end of the decision service life and

   c) realizing the "required return rate" specified for each decision.

Given that the possible options to be decided upon are necessarily discrete; a decision sequence which exactly covers a given forecast period is necessarily accidental. Therefore, only maximal sequences can be considered which are defined as follows.

Given a forecast period, a maximal sequence of this period is a sequence which is within the period and exceeds the period when whatever decision is added.

The end of a maximal sequence depends on the options selected at various stages. Given the forecast period, it, in general, varies from one sequence to another. When the forecast period is extended, each of its maximal sequences can be continued and produces a set of extended maximal sequences (which then have the maximal sequence involved as a common subsequence). Specifically:

Any finite decision sequence is maximal within some forecast period and is a common subsequence of the members of some set of extended maximal sequences.

Thus, the optimality criterion implies that:

Given a forecast period, the longest sequence which is a subsequence of the optimal sequence and is contained in this period is a subsequence of at least one maximal sequence of the given forecast period.

This sequence will be called "maximal optimal sequence" for the given forecast period. Its existence and uniqueness will be proved by the optimization procedure developed in Section 4.

The optimality criterion then states that:

Given a forecast period of sufficient length,[3] the corresponding "maximal optimal sequence" can be determined independently of future forecast exensions and continued along with future forecast extensions.

Thus, the optimality criterion satisfies the necessary condition that: the optimal sequence is independent of the way it is formed, in particular of the forecast periods which are available.

The criterion is unequivocal as has been explained in Section 2.2.1. It concretizes:

a) the industrial objective which is: produce at minimum cost and

b) the planning objective which is: plan the immediate future in consideration of the predictable future and without cutting out the not yet predictable one.

As the "required return rate" can vary with the decision time, it can be specified in accordance with the project risks and the money market conditions which prevail at the investment time.

In short, the optimal planning problem stated by the above optimality criterion is factual, specific and complete.

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3 The length of a forecast period must at least equal the total length of the first two decisions of the optimal sequence, as will be seen in Section 4.

3. COST FUNCTION

3.1 Definition

The "required gross revenues" of a decision is, at any time, the product of the selling price per demand unit by the demand that the decision serves at that time. This leads to the cost function defined below.

Given the demand served by a decision as a function of time,

Given the "required return rate",

Given the operating expenses and capital expenditures incurred by the decision,

Given the service life of the decision,

The "required gross revenues per demand unit" is the price it is required to charge each demand unit so that the net revenues derived from the sale during the decision service life:

a) repay all capital expenditures fully at the end of the decision service life and

b) realize the "required return rate".

3.2 Formulation

Let:

a) S be the maximum production capacity of the decision,

b) L, the decision service life,

c) $n_i \leq S$, the demand served by the decision during time unit i for $i=1,2,..,L$,

d) C_i, the capital expenditure incurred at time i for $0 \leqslant i < L$,

e) O_i, the operating expenses during time unit i for i=1,2,...,L (management, labour, maintenance, material, floor space, utilities, any taxes except taxes on revenues, etc.)

f) D_i, the income tax deduction for time unit i ($\geqslant 1$), accounting for capital depreciation, debt interest and salvages,

g) s_i, the net salvage in time unit i for $i \leqslant L$

h) r, the "required return rate",

i) t, the income tax rate,

j) $f_i A$ the "required gross revenues per demand unit" in time unit $i \leqslant L$, where f_i is a given function of time specifying the variation estimated for the selling price per demand unit during the decision service life.

Then, the base "required gross revenues per demand unit", A, is:

$$A = \frac{\sum_{i=0}^{L-1}(1+r)^{-i}C_i + (1-t)\sum_{i=1}^{L}(1+r)^{-i}(O_i - s_i) - t\sum_{i=1}^{\infty}(1+r)^{-i}D_i}{(1-t)\sum_{i=1}^{L}(1+r)^{-i} f_i n_i}$$

The above formula simply expresses the basic "loan repayment equation" in which the net revenues are expressed in terms of gross revenues, operating expenses, depreciation allowances salvages and the tax rate.

D_i is determined by the depreciation method applied. $f_i n_i A$ is the "required gross revenues" of the decision at time i for $0 < i \leqslant L$.

3.3 Properties

The costs incurred by a decision can be partitioned into:

a) one component which is independent or practically independent of the maximum production capacity of the decision and

b) one component which depends directly on this production capacity.

Correspondingly, the "required gross revenues per demand unit" has:

a) one component which monotonously decreases as the decision maximum capacity increases and

b) one component which monotonously increases with the decision maximum capacity.

The increase of the second component can be explained as follows: As the decision maximum capacity increases, the decision fill period grows longer; a larger portion of this capacity stays idle longer and is also productive for a shorter period since the decision service life is finite.

Thus, as a function of the decision maximum capacity, the "required gross revenues per demand unit has a unique minimum (Figure 1). This minimum will be called a local minimum and the corresponding decision, a locally optimal decision.

A local minimum optimizes the economy of scale but does not necessarily optimize the long term effect of a decision. To this purpose, the optimization algorithm (Section 4) will generalize this local minimum principle to what will be called the difference of two decisions and defined by the differences of the corresponding costs and production capacities.

As formulated in Section 3.2, the "required gross revenues per demand unit" comprehensively and unequivocally measures how well the production capacity and costs of a decision match with the demand to be served and the " return rate" to be realized. It is a consistent basis for comparing options highly different in production capacity. It also makes it consistent to compare options highly diverse in service features or production lines since a normalized demand unit can always be defined.

In the evaluation of projects, the project optimal implementation and the corresponding minimum "required gross revenues per demand unit" take on special significance:

a) If the project optimal implementation is carried out and the demand is charged at the "minimum required gross revenues per demand unit", then the resulting net revenues realize the "required return rate" exactly.

b) If the demand is charged at the "minimum required gross revenues per demand unit", but the project is not implemented as optimally planned, then the "required return rate" cannot be realized.

c) If the demand is charged below the "minimum required gross revenues per demand unit", then in no way the project can be implemented to realize the "required return rate".

d) If the demand can be charged higher than the "minimum required gross revenues per demand unit", then the "required return rate" should be increased and the project optimal implementation, accordingly determined, so that the project profitability (return rate) can be maximized (Section 2.2.2).

4. OPTIMIZATION ALGORITHM

4.1 Principle

The costs of a decision are shared by the demand that the decision serves during its service life. Limited to the decision maximum capacity, this portion of demand is substracted from both sharing and adding to the costs of future decisions. Thus, the decisions partition the demand into independent cost groups.

The rule in this partitioning process is as follows:

a) The length of a decision must at least equal the length of the corresponding locally optimal decision (Section 3.3), so as to optimize the decision of scale;

b) This minimum length is then extended by appropriate steps (to be determined) until a further extension results in serving the additional demand at "required gross revenues per demand unit" higher than those of the corresponding locally optimal decision, so as to optimize the long term effect of the decision.

This optimization principle totally expresses the long term effect of a decision since:

a) each decision so determined serves its demand at "required gross revenues" lower than any other alternatives; the corresponding demand is also the maximum which can be advantageously served by one decision; and

b) the long term effect of a decision ends at determining the time of the next decision; the latter cuts off any interaction further down the sequence.

The "difference of decisions" is defined below to model the long term effect expressed above for a decision.

4.2 Difference of Decisions

Let S and S' satisfy S S' and be the capacities of two options available at decision time, say, O.

For simplicity, let S and S' also denote the respective options.

Let (O,t) be the fill period of S if S is the decision at time O.

Then the difference S'-S is a virtual option defined for decision time O as follows:

a) the service life of S'-S is that of S';

b) the operating expenses and capital expenditures of S'-S are, at any time, the algebraic differences of the operating expenses and capital expenditures that S' and S respectively incur as though they are decisions at time O;

c) S'-S serves the demand in excess of S up to S'-S from time t to the end of the service life of S or S' whichever is the shorter;

d) S'-S serves the whole demand up to S' thereafter if S has the shorter service life[4].

The "required" gross revenues per demand unit" of the difference S'-S, so characterized, are then the charge per unit incurred by the demand of S'-S (and this demand alone) for repayment of the costs of S'-S. This implied substitution of S' for S leaves the "required gross revenues per demand unit" unchanged for the demand previously served by S.

The optimization procedure straightly follows.

4.3 Optimization Procedure

Let the forecast period be of sufficient length (i.e. at least contain the first decision of the optimal sequence and the next locally optimal decision). Let O be the time of the first decision.

Let the required return rate be given as a function of decision time.

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[4]The definition of S'-S is general since the demand need not be an increasing function of time and the options can have different service lives.

4.3.1 Step One

Let $S_{min.1}$ be the capacity of the locally optimal decision at time O (Section 3.3) and $Y_{min.1}$ the corresponding local minimum of required gross revenues per demand unit".

Then $Y_{min.1}$ is the lowest "required gross revenues per demand unit" for the demand served by a decision at time O, and $S_{min.1}$ is the maximum demand which can be served that low.

If $S_{min.1}$ is the largest capacity of the set, say T_O, of options available at time O, then $S_{min.1}$ is (by default) the first decision of the optimal sequence.

If there exist capacities larger than $S_{min.1}$ in T_O, then $S_{min.1}$ is a lower bound of this first decision and the optimization process continues as follows.

4.3.2 Step Two

Let (O,t_1) be the fill period of $S_{min.1}$, i.e. the longest interval during which the demand at most equals $S_{min.1}$ [5].

Let $S_{min.2}$ be the capacity of the locally optimal decision determined for: decision time t_1, the demand in excess of $S_{min.1}$ from time t_1 on, and the options available at time t_1; and let $Y_{min.2}$ be the corresponding local minimum of required gross revenues per demand unit.

For $S > S_{min.1}$ and $S \in T_O$, let the "required gross revenues per demand unit" of the difference $S-S_{min.1}$ be minimum when $S=S'$, and let Y' denote this minimum (which is unique, Section 3.3).

If $Y' \geqslant Y_{min.2}$, then $S_{min.1}$ is the first decision of the optimal sequence (since the demand that $S'-S_{min.1}$ can serve is served cheaper by $S_{min.2}$).

If $Y' < Y_{min.2}$, then Y' is the lowest "required gross revenues per demand unit" for the demand in excess of $S_{min.1}$; and the demand that $S'-S_{min.1}$ serves is the maximum which can be served that low.

Thus, S' is the new lower bound of the first decision of the optimal sequence. S' serves the combined demands of $S_{min.1}$ and $S'-S_{min.1}$ cheaper than any other alternatives since S' produces the local minima $Y_{min.1}$ and Y'.

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[5] The demand need not be an increasing function of time.

If S' is the largest capacity of T_O, then S' is (by default) the first decision of the optimal sequence.

If there exist capacities larger than S' in T_O, then the optimization process continues as follows.

4.3.3. Step Three

Let (O, t') be the fill period of S'.

Substituting S' for $S_{min.1}$ and t' for t_1, Step Two is repeated and so on.

The process continues so until:

a) either T_O is exhausted,

b) or the locally optimal difference serves the additional demand at "required gross revenues per demand unit" higher than the corresponding locally optimal decision.

Let $S_{opt.1}$ denote the final capacity so determined.

Then $S_{opt.1}$ is the first decision of the optimal sequence, and will be call first optimal decision.

Similarly, the second optimal decision is determined to serve the demand which is in excess of $S_{opt.1}$ during $S_{opt.1}$ service life and includes $S_{opt.1}$ thereafter.

The procedure continues so indefinitely as long as and when forecasts are available.

4.3.4. Properties of The Optimal Sequence

An optimal decision, say $S_{opt.1}$, is determined as the first locally optimal decision followed by a sequence of locally optimal differences of decisions. At any time during its service life, $S_{opt.1}$ therefore produces the local minimum of required gross revenues per demand unit;

and serves its demand at minimum "required gross revenues" in the long run (i.e. at lower required gross revenues than any other alternatives).

In the extension process, the local minimum of required gross revenues per demand unit strictly increases as the extension steps advance. The maximum length is therefore attained for the first decision when the process stops. Thus, $S_{opt.1}$ optimizes the long term effect of the first decision and is the maximum demand to be served by the first decision.

As the above holds true for any optimal decisions, the ensuing optimal sequence minimizes the "required gross revenues" at any time over its length, hence over an indefinite period since the sequence can be indefinitely continued with future forecast extensions. Thus,

The optimal sequence implements the optimality criterion stated in Section 2.3 and solves the planning problem of Section 2.1.

4.4. Merits of the Optimization Procedure

The optimization procedure just described is general since it applies to any planning situations and assumes no restrictions on the demand to be dealt with and the technologies to be applied.

Planning situations may appear complexe and confusing in practice. However, they always resolve to the basic problem solved here since, the planning situations analyzed in Sections 2.2.1 and 2.2.2 are exclusive. The impossibility to do so indicates that the problem is inconsistently stated.

Conceptual evaluators such as the classical ones are not only unnecessary; they are void and misleading since they model an imaginary situation, but not an approximation.

The procedure is rigorous operationally, anlytically and logically. It complies with all facts and conditions of investment and planning. It satisfies the principle of financial independence of decisions and properly models the long term effect of a decision. It resorts to no unrealizable assumptions, in particular those that the classical procedure implies as consequences of planning over a closed period, namely: demand freeze at the end of the planning period, co-termination of decision sequences under comparison, identical gross revenues for the entire life cycles of the decision sequences and plant repetition (i.e. plants are replaced by the same plants at the same costs at the end of their services lives). The ambiguous concept of " project or corporate internal return rate" is also eliminated. The "required return rate" involved in the procedure is simply the interest rate that the decision must realize in competition with other opportunities of investing the required capital. It is to be specified for each decision in accordance with the project risks and the conditions of the money market at the decision time.

The procedure is simple to implement since it requires no sequences to generate and has but one formula (Section 3.2) to code.

The procedure is exceptionally fast since it is sequential but not combinatorial. If n (for example 10) is the number of options available at each decision time, and m (for example 10), the number of decision stages, then the corresponding optimal sequence is determined in less than mn^2 (10^3 in the example) calculations of one formula, again n^m (10^{10} in the example) sequences to be generated and compared in the classical combinatorial procedure.

In most planning studies, only the first decision is intended for execution; the decision sequence that the classical procedures is required to produce is merely for consideration of the decision long term effect. In this procedure, only the first optimal decision need be determined for such studies since it inherently and totally renders this effect[6]. Thus the computing time is further reduced by the factor m (10 in the example).

The procedures makes optimal long term planning practical and concrete. It integrates the optimal short term plans to be executed into the optimal long term plan for overall evaluation of the project. Each optimal decision is determined over a minimum forecast length, and its dependability depends uniquely on the reliability of this forecast period. In particular it is completely independent of future forecast revisions which are one "locally optimal decision length" away. Thus the relatively high reliability of short term forecast is fully exploited.

In short, the proposed planning solution is complete.

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[6]Forming a decision through optimizing a whole sequence of decisions is intuitively appealing. However, it contains serious operational and logical inconsistencies which lead to the wrong decision. This is an interesting and important subject to be analyzed and discussed fully in a general theory of optimization and control.

5. CONCLUSION

This planning method departs from the classical one in its cost function, its model for the long term effect of an investment decision and its optimization procedure, which is analytical and sequential. It results from a thorough analysis of the facts and conditions involved in planning.

The substitution of the method for the classical one requires the development of new planning procedures and tools. However, the benefits of the true optimal solution recommend it. The classical method also provides no suitable tools in many cases.

In designing connecting networks (telecommunications, transport, distribution), this method can be applied to produce the optimal distribution of operation centers and the optimal routes and sizes of connecting links (Ref. 2,3). In partitioning hardware into modules, the method permits the formulation of the optimal modules in terms of production cost, maintenance cost, inventory cost, failure rate and service quality (Ref. 4).

More generally, the cost function of the method permits a consistent, comprehensive comparison of alternatives which are widely diverse in technical and operational features.

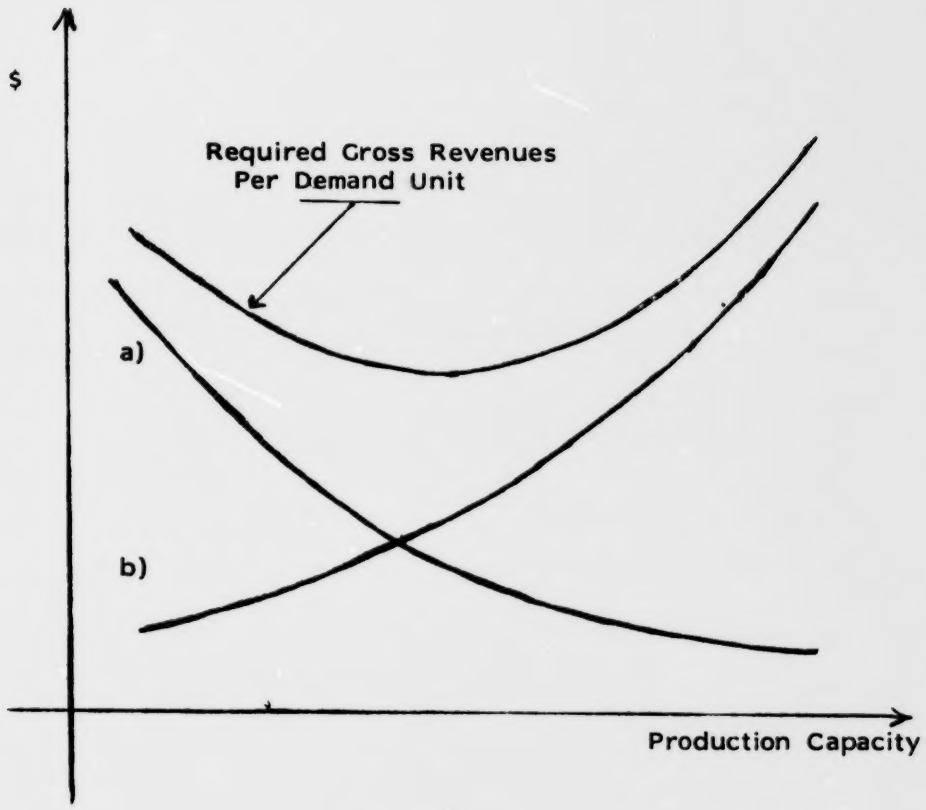

Figure 1: Required Gross Revenues Per Demand Unit and its components.